

Wherefore, what is claimed is:

5 1. A process for encoding bi-level images, said process comprising
using a computing apparatus to perform the following process actions:
 for each pixel location in raster order in the bi-level image,
 predicting a binary value for the pixel at a pixel location
under consideration based on its context, wherein a context of a pixel refers to
predicted values of a prescribed pattern of pixels preceding the pixel in raster
10 order;
 determining whether the predicted pixel value matches the
actual pixel value for the pixel location under consideration; and
 compressing the data concerning at which pixel locations the
predicted pixel values match and do not match the actual values using a context-
15 dependent, backward adaptive, Run-Length-Rice encoding technique.

 2. The process of Claim 1, wherein the process action of predicting
the binary value for the pixel at each pixel location in raster order, comprises the
actions of:
20 assigning a prescribed initial probability value to each of a set of
potential context indexes, wherein a context index is a binary word comprising
previously predicted binary values of a prescribed pattern of pixels of the bi-level
image preceding in raster order a pixel whose value is currently being predicted,
and wherein the initial probability value indicates the probability that the pixel
25 whose value is currently being predicted has a first binary value associated with
a first of the two colors of the bi-level image based on the predicted values of the
prescribed pattern of pixels preceding the pixel being predicted; and
 for each pixel location in raster order in the bi-level image,
 computing the context index associated with the prescribed
30 pattern of pixels preceding the pixel location under consideration, wherein pixel

locations in the pattern that fall outside the bi-level image are considered to have the first binary value,

identifying the probability value assigned to the computed context index,

5 whenever the identified probability value indicates that the pixel location under consideration is more likely than not to have the first binary value, assigning as the predicted pixel value for that location the first binary value, and

10 whenever the identified probability value indicates that the pixel location under consideration is not more likely than not to have the first binary value, assigning as the predicted pixel value for that location the second binary value associated with a second of the two colors of the bi-level image.

15 3. The process of Claim 2, wherein the first binary value associated with the first of the two colors of the bi-level image is a 0, and the second binary value associated with the second of the two colors of the bi-level image is a 1.

20 4. The process of Claim 2, wherein the first of the two colors of the bi-level image is white, and the second of the two colors is black.

25 5. The process of Claim 2, wherein the process action of assigning a prescribed initial probability value to each of a set of potential context indexes, comprises an action of assigning the same initial probability value to each context index, said initial probability being a number indicative of a 0.50 probability that the pixel value has the first binary value.

30 6. The process of Claim 2, further comprising a process action of adjusting the probability value assigned to the computed context index by increasing it by a prescribed amount if the predicted pixel value of the pixel location under consideration is assigned the first binary value and decreasing it

by a prescribed amount if the predicted pixel value is assigned the second binary value.

7. The process of Claim 6, wherein the probability values are scaled so as to range between 0 and prescribed maximum integer number, and wherein the process action of adjusting the probability value assigned to the computed context index comprises an action of making the adjustments in integer increments.

8. The process action of Claim 7, wherein the process action of adjusting the probability value assigned to the computed context index further comprises the actions of:

whenever decreasing the scaled probability value would result in a value of less than 0, making the probability value 0; and

whenever increasing the scaled probability value would result in a value of greater than the prescribed maximum minus one, making the probability value equal to the prescribed maximum minus one.

9. The process of Claim 7, wherein the prescribed maximum integer number is eight.

10. The process of Claim 1, wherein the process action of determining whether the predicted pixel value matches the actual pixel value for the pixel location under consideration, comprises the actions of:

comparing the predicted pixel value to the actual pixel value of the pixel location under consideration; and

assigning a prediction error value to the pixel location, wherein the prediction error value has a first binary value if the predicted pixel value matches the actual pixel value and a second binary value if the predicted pixel value is different from the actual pixel value.

11. The process of Claim 10, wherein the first binary value associated with the prediction error values is a 0, and the second binary value associated with the prediction error values is a 1.

5 12. The process of Claim 1, wherein the process action of compressing the data concerning at which pixel locations the predicted pixel values do not match the actual values, comprises the actions of:

assigning a prescribed initial k value to each context index, wherein a k value is used to compute a number representing a string of consecutive,
10 raster ordered, prediction error values having the first binary value;

identifying the k value assigned to the context index computed for the first pixel location in the bi-level image and subsequently for each pixel location that follows in raster order a pixel that triggered a codeword to be established; and

15 for each pixel location in the bi-level image beginning with the first and proceeding in raster order,

determining if the prediction error value assigned to the pixel location under consideration has the first or second binary value,

20 whenever the prediction error value assigned to the pixel location under consideration has the first value, taking no action unless the number of preceding pixels locations for which no action has been taken equals the last-identified k value, and if it does equal this k value, establishing a first type of codeword by representing the number of preceding pixel locations for which no action has been taken with a single first value, and

25 whenever the prediction error value assigned to the pixel location under consideration has the second value, establishing a second type of codeword by representing the prediction error having the second value and the number of preceding pixel locations for which no action has been taken with a second value and a binary word indicating the number of preceding pixel
30 locations for which no action has been taken.

13. The process of Claim 12, further comprising the process action of computing the number representing the string of consecutive, raster ordered, prediction error values having the first binary value from an assigned k value using the equation 2^k .

14. The process of Claim 12, wherein the first value associated with the first type of codeword is a 0, and the second value associated with the second type of codeword is a 1.

15. The process of Claim 12, wherein the process action of assigning a prescribed initial k value to each context index, comprises an action of assigning the same initial k value to each context index, said initial k value being preferably chosen as two.

16. The process of Claim 12, further comprising the process action of whenever a codeword is established, adjusting the k value assigned to the context index associated with pixel location that begins the string of prediction error values represented by that codeword by increasing it by a prescribed amount if the codeword is of the first type and decreasing it by a prescribed amount if the codeword is of the second type.

17. The process of Claim 16, wherein the k values are scaled by multiplying each by a prescribed scaling factor.

18. The process of Claim 17, wherein the prescribed amount that the scaled k values are increased or decreased depends on how many times the k values has been adjusted from its initial value.

19. The process of Claim 18, wherein the prescribed scaling factor equals 16, the prescribed amount that a k value is increased is 3, 3, 4, 5, and 6

for the first through fifth times it is consecutively increased, respectively, and 8 for each time it is consecutively increased after the fifth time.

20. The process of Claim 19, the prescribed amount that a k value is decreased is 0, 3, 6, 6, 8 and 10 for the first through sixth times it is consecutively decreased, respectively, and 12 for each time it is consecutively decreased after the sixth time.

21. A process for decoding a bi-level image encoded by a process that reduces the image data to a series of codewords from which can be derived prediction error values indicating whether the pixel values of each pixel location in the bi-level image had a first binary value or a second binary value, said codewords coming in two types a first of which is a first value representing a number of pixel locations that have a first binary prediction error value and the second of which comprises a second value followed by a binary word that indicates the number of pixel locations preceding a location having a second binary prediction error value that exhibit the first binary prediction error value, said process comprising using a computing apparatus to perform the following process actions:

receiving the series of codewords;

for each pixel location in raster order in a restoration image of the encoded bi-level image;

predicting a binary value for the pixel at the pixel location under consideration based on its context, wherein a context of a pixel refers to predicted values of a prescribed pattern of pixels preceding the pixel in raster order,

deriving a prediction error value for the pixel location under consideration from a received codeword;

comparing in raster order the prediction error assigned to a pixel location of the restoration image and the predicted pixel value for that location using an exclusive OR process such that whenever the prediction error value is

the first binary value the corresponding predicted pixel value is not changed, and whenever the prediction error value is the second binary value the corresponding predicted pixel value is flipped to its opposite binary value; and

designating the result of each prediction error and predicted pixel value comparison as a restored pixel value for the associated pixel location in the restoration image.

22. The process of Claim 21, wherein the process action of predicting a binary value for the pixel at each pixel location, comprises the actions of:

assigning a prescribed initial probability value to each of a set of potential context indexes which is identical to those used in encoding the bi-level image, wherein a context index is a binary word comprising previously predicted binary values of a prescribed pattern of pixels of the bi-level image preceding in raster order a pixel whose value is currently being predicted, and wherein the initial probability value indicates the probability that the pixel whose value is currently being predicted has a first binary value associated with a first of the two colors of a restoration image of the encoded bi-level image based on the predicted values of the prescribed pattern of pixels preceding the pixel being predicted; and

for each pixel location in raster order in the restoration image of the encoded bi-level image upon receiving the first of the series of codewords,

computing the context index associated with the prescribed pattern of pixels preceding the pixel location under consideration, wherein pixel locations in the pattern that fall outside the bi-level image are considered to have the first binary value,

identifying the probability value assigned to the computed context index,

whenever the identified probability value indicates that the pixel location under consideration is more likely than not to have the first binary value, assigning as the predicted pixel value for that location the first binary value, and

whenever the identified probability value indicates that the pixel location under consideration is not more likely than not to have the first binary value, assigning as the predicted pixel value for that location the second binary value associated with a second of the two colors of the bi-level image.

5

23. The process of Claim 22, wherein the first binary value associated with the first of the two colors of the bi-level image is a 0, and the second binary value associated with the second of the two colors of the bi-level image is a 1.

10

24. The process of Claim 22, wherein the first of the two colors of the bi-level image is white, and the second of the two colors is black.

15

25. The process of Claim 22, further comprising a process action of adjusting the probability value assigned to the computed context index by increasing it by the prescribed amount used in encoding the bi-level image if the predicted pixel value of the pixel location under consideration is assigned the first binary value and decreasing it by the prescribed amount used in encoding the bi-level image if the predicted pixel value is assigned the second binary value.

20

26. The process of Claim 25, wherein the probability values are scaled so as to range between 0 and a prescribed maximum integer number identical to that used in the encoding of the bi-level image, and wherein the process action of adjusting the probability value assigned to the computed context index comprises the actions of:

25

making the adjustments in integer increments;

making the probability value 0, whenever decreasing the scaled probability value would result in a value of less than 0; and

30

making the probability value equal to the prescribed maximum minus one, whenever increasing the scaled probability value would result in a value of greater than the prescribed maximum minus one.

27. The process of Claim 21, wherein the process action of deriving a prediction error value for each pixel location in raster order in a restoration image, comprises the actions of:

5 assigning a prescribed initial k value to each context index that is identical to the value used in encoding the bi-level image, wherein a k value is used to compute a number representing a string of consecutive, raster ordered, prediction error values having the first binary value in the same manner employed in encoding the bi-level image being decoded;

10 determining if the last-received codeword is of the first or second type;

15 whenever the last-received codeword is of the second type, assigning prediction error values having the first binary value to the number of previously-unassigned pixel locations in a restoration of the encoded bi-level image in raster order starting with the earliest non-assigned location that are indicated by the binary word component of the codeword and assigning a prediction error value having the second binary value to the pixel location following those newly assigned pixel locations; and

20 whenever the last-received codeword is of the first type, identifying the k value assigned to the context index associated with the earliest pixel location in the restoration image not yet assigned a prediction error value, and

25 assigning prediction error values having the first binary value to the number of previously-unassigned pixel locations that are indicated by the identified k value in the restoration image in raster order starting with the earliest non-assigned location.

28. The process of Claim 27, wherein the first value associated with the first type of codeword is a 0, and the second value associated with the second type of codeword is a 1.

29. The process of Claim 27, further comprising the process action of, upon completion of assigning prediction error values in connection with the processing of the last-received codeword, adjusting the k value assigned to the context index associated with pixel location that begins the string of prediction error values just assigned by increasing the k value by a prescribed amount employed in the encoding of the bi-level image being decoded if the codeword is of the first type and decreasing the k value by a prescribed amount employed in the encoding of the bi-level image being decoded if the codeword is of the second type.

30. The process of Claim 29, wherein the k values are scaled by multiplying each by a prescribed scaling factor employed in the encoding of the bi-level image being decoded.

31. A system for encoding bi-level images, comprising:
a general purpose computing device; and
a computer program comprising program modules executable by the computing device, wherein the computing device is directed by the program modules of the computer program to,
assign a prescribed initial probability value to each of a set of potential context indexes, wherein a context index is a binary word comprising previously predicted binary values of a prescribed pattern of pixels of the bi-level image preceding in raster order a pixel whose value is currently being predicted, and wherein the initial probability value indicates the probability that the pixel whose value is currently being predicted has a first binary value associated with a first of the two colors of the bi-level image based on the predicted values of the prescribed pattern of pixels preceding the pixel being predicted for each pixel location in raster order in the bi-level image,
predict a binary value for each pixel location in raster order in the bi-level image by,

computing the context index associated with the prescribed pattern of pixels preceding the pixel location under consideration, wherein pixel locations in the pattern that fall outside the bi-level image are considered to have the first binary value,

5 identifying the probability value assigned to the computed context index,

assigning as the predicted pixel value for that location the first binary value whenever the identified probability value indicates that the pixel location under consideration is more likely than not to have the first binary value,

10 assigning as the predicted pixel value for that location the second binary value associated with a second of the two colors of the bi-level image whenever the identified probability value indicates that the pixel location under consideration is not more likely than not to have the first binary value,

15 adjusting the probability value assigned to the computed context index by increasing it by a prescribed amount if the predicted pixel value of the pixel location under consideration is assigned the first binary value and decreasing it by a prescribed amount if the predicted pixel value is assigned the second binary value,

20 for each pixel location in raster order in the bi-level image, determine whether the predicted pixel value matches the actual pixel value for the pixel location under consideration by,

comparing the predicted pixel value to the actual pixel value of the pixel location under consideration, and

25 assigning a prediction error value to the pixel location, wherein the prediction error value has a first binary value if the predicted pixel value matches the actual pixel value and a second binary value if the predicted pixel value is different from the actual pixel value, and

30 compress the data concerning at which pixel locations the predicted pixel values do not match the actual values using a bi-level image encoding technique.

32. A system for decoding bi-level images encoded by a process that reduces the image data to a series of codewords from which can be derived prediction error values indicating whether the pixel values of each pixel location in the bi-level image had a first binary value or a second binary value, said
5 codewords coming in two types a first of which is a first value representing a number of pixel locations that have a first binary prediction error value and the second of which comprises a second value followed by a binary word that together indicate the number of pixel locations preceding a location having a
10 second binary prediction error value that exhibit the first binary prediction error value, comprising:

a general purpose computing device; and

a computer program comprising program modules executable by the computing device, wherein the computing device is directed by the program
15 modules of the computer program to,

receive the series of codewords,

assign a prescribed initial probability value to each of a set of potential context indexes which is identical to those used in encoding the bi-level image, wherein a context index is a binary word comprising previously
20 predicted binary values of a prescribed pattern of pixels of the bi-level image preceding in raster order a pixel whose value is currently being predicted, and wherein the initial probability value indicates the probability that the pixel whose value is currently being predicted has a first binary value associated with a first of the two colors of a restoration image of the encoded bi-level image based on the
25 predicted values of the prescribed pattern of pixels preceding the pixel being predicted; and

predict a binary value for each pixel location in raster order in a restoration image of the encoded bi-level image by, upon receiving the first of the series of codewords,

30 computing the context index associated with the prescribed pattern of pixels preceding the pixel location under consideration,

wherein pixel locations in the pattern that fall outside the bi-level image are considered to have the first binary value,

identifying the probability value assigned to the computed context index,

5 assigning as the predicted pixel value for that location the first binary value whenever the identified probability value indicates that the pixel location under consideration is more likely than not to have the first binary value, and

10 assigning as the predicted pixel value for that location the second binary value associated with a second of the two colors of the bi-level image whenever the identified probability value indicates that the pixel location under consideration is not more likely than not to have the first binary value,

15 adjusting the probability value assigned to the computed context index by increasing it by the prescribed amount used in encoding the bi-level image if the predicted pixel value of the pixel location under consideration is assigned the first binary value and decreasing it by the prescribed amount used in encoding the bi-level image if the predicted pixel value is assigned the second binary value,

20 derive a prediction error value for each pixel location in raster order in a restoration image of the encoded bi-level image from a received codeword,

25 compare in raster order the prediction error assigned to a pixel location of the restoration image and the predicted pixel value for that location using an exclusive OR process such that whenever the prediction error value is the first binary value the corresponding predicted pixel value is not changed, and whenever the prediction error value is the second binary value the corresponding predicted pixel value is flipped to its opposite binary value, and

30 designate the result of each prediction error and predicted pixel value comparison as a restored pixel value for the associated pixel location in the restoration image.

33. A computer-readable medium having computer-executable instructions for encoding bi-level images, said computer-executable instructions comprising:

for each pixel location in raster order in the bi-level image,

5 predicting a binary value for the pixel at a pixel location under consideration based on its context, wherein a context of a pixel refers to predicted values of a prescribed pattern of pixels preceding the pixel in raster order;

10 determining whether the predicted pixel value matches the actual pixel value for the pixel location under consideration; and

compressing the data concerning at which pixel locations the predicted pixel values match and do not match the actual values by,

15 assigning a prescribed initial k value to each context index, wherein a k value is used to compute a number representing a string of consecutive, raster ordered, prediction error values having the first binary value,

identifying the k value assigned to the context index computed for the first pixel location in the bi-level image and subsequently for each pixel location that follows in raster order a pixel that triggered a codeword to be established,

20 for each pixel location in the bi-level image beginning with the first and proceeding in raster order,

determining if the prediction error value assigned to the pixel location under consideration has the first or second binary value,

25 whenever the prediction error value assigned to the pixel location under consideration has the first value, taking no action unless the number of preceding pixels locations for which no action has been taken equals the last-identified k value, and if it does equal this k value, establishing a first type of codeword by representing the number of preceding pixel locations for which no action has been taken with a single first value, and

30 whenever the prediction error value assigned to the pixel location under consideration has the second value, establishing a second

assigning a prescribed initial k value to each context index that is identical to the value used in encoding the bi-level image, wherein a k value is used to compute a number representing a string of consecutive, raster ordered, prediction error values having the first binary value in the same manner employed in encoding the bi-level image being decoded,

determining if the last-received codeword is of the first or second type,

whenever the last-received codeword is of the second type, assigning prediction error values having the first binary value to the number of previously-unassigned pixel locations in a restoration of the encoded bi-level image in raster order starting with the earliest non-assigned location that are indicated by the binary word component of the codeword and assigning a prediction error value having the second binary value to the pixel location following those newly assigned pixel locations, and

whenever the last-received codeword is of the first type,

identifying the k value assigned to the context index associated with the earliest pixel location in the restoration image not yet assigned a prediction error value, and

assigning prediction error values having the first binary value to the number of previously-unassigned pixel locations that are indicated by the identified k value in the restoration image in raster order starting with the earliest non-assigned location, and

upon completion of assigning prediction error values in connection with the processing of the last-received codeword, adjusting the k value assigned to the context index associated with pixel location that begins the string of prediction error values just assigned by increasing the k value by a prescribed amount employed in the encoding of the bi-level image being decoded if the codeword is of the first type and decreasing the k value by a prescribed amount employed in the encoding of the bi-level image being decoded if the codeword is of the second type;

comparing in raster order the prediction error assigned to a pixel location of the restoration image and the predicted pixel value for that location using an exclusive OR process such that whenever the prediction error value is the first binary value the corresponding predicted pixel value is not changed, and
5 whenever the prediction error value is the second binary value the corresponding predicted pixel value is flipped to its opposite binary value;

designating the result of each prediction error and predicted pixel value comparison as a restored pixel value for the associated pixel location in the restoration image.

10

11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65
66
67
68
69
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
91
92
93
94
95
96
97
98
99
100
101
102
103
104
105
106
107
108
109
110
111
112
113
114
115
116
117
118
119
120
121
122
123
124
125
126
127
128
129
130
131
132
133
134
135
136
137
138
139
140
141
142
143
144
145
146
147
148
149
150
151
152
153
154
155
156
157
158
159
160
161
162
163
164
165
166
167
168
169
170
171
172
173
174
175
176
177
178
179
180
181
182
183
184
185
186
187
188
189
190
191
192
193
194
195
196
197
198
199
200
201
202
203
204
205
206
207
208
209
210
211
212
213
214
215
216
217
218
219
220
221
222
223
224
225
226
227
228
229
230
231
232
233
234
235
236
237
238
239
240
241
242
243
244
245
246
247
248
249
250
251
252
253
254
255
256
257
258
259
260
261
262
263
264
265
266
267
268
269
270
271
272
273
274
275
276
277
278
279
280
281
282
283
284
285
286
287
288
289
290
291
292
293
294
295
296
297
298
299
300
301
302
303
304
305
306
307
308
309
310
311
312
313
314
315
316
317
318
319
320
321
322
323
324
325
326
327
328
329
330
331
332
333
334
335
336
337
338
339
340
341
342
343
344
345
346
347
348
349
350
351
352
353
354
355
356
357
358
359
360
361
362
363
364
365
366
367
368
369
370
371
372
373
374
375
376
377
378
379
380
381
382
383
384
385
386
387
388
389
390
391
392
393
394
395
396
397
398
399
400
401
402
403
404
405
406
407
408
409
410
411
412
413
414
415
416
417
418
419
420
421
422
423
424
425
426
427
428
429
430
431
432
433
434
435
436
437
438
439
440
441
442
443
444
445
446
447
448
449
450
451
452
453
454
455
456
457
458
459
460
461
462
463
464
465
466
467
468
469
470
471
472
473
474
475
476
477
478
479
480
481
482
483
484
485
486
487
488
489
490
491
492
493
494
495
496
497
498
499
500
501
502
503
504
505
506
507
508
509
510
511
512
513
514
515
516
517
518
519
520
521
522
523
524
525
526
527
528
529
530
531
532
533
534
535
536
537
538
539
540
541
542
543
544
545
546
547
548
549
550
551
552
553
554
555
556
557
558
559
560
561
562
563
564
565
566
567
568
569
570
571
572
573
574
575
576
577
578
579
580
581
582
583
584
585
586
587
588
589
590
591
592
593
594
595
596
597
598
599
600
601
602
603
604
605
606
607
608
609
610
611
612
613
614
615
616
617
618
619
620
621
622
623
624
625
626
627
628
629
630
631
632
633
634
635
636
637
638
639
640
641
642
643
644
645
646
647
648
649
650
651
652
653
654
655
656
657
658
659
660
661
662
663
664
665
666
667
668
669
670
671
672
673
674
675
676
677
678
679
680
681
682
683
684
685
686
687
688
689
690
691
692
693
694
695
696
697
698
699
700
701
702
703
704
705
706
707
708
709
710
711
712
713
714
715
716
717
718
719
720
721
722
723
724
725
726
727
728
729
730
731
732
733
734
735
736
737
738
739
740
741
742
743
744
745
746
747
748
749
750
751
752
753
754
755
756
757
758
759
760
761
762
763
764
765
766
767
768
769
770
771
772
773
774
775
776
777
778
779
780
781
782
783
784
785
786
787
788
789
790
791
792
793
794
795
796
797
798
799
800
801
802
803
804
805
806
807
808
809
810
811
812
813
814
815
816
817
818
819
820
821
822
823
824
825
826
827
828
829
830
831
832
833
834
835
836
837
838
839
840
841
842
843
844
845
846
847
848
849
850
851
852
853
854
855
856
857
858
859
860
861
862
863
864
865
866
867
868
869
870
871
872
873
874
875
876
877
878
879
880
881
882
883
884
885
886
887
888
889
890
891
892
893
894
895
896
897
898
899
900
901
902
903
904
905
906
907
908
909
910
911
912
913
914
915
916
917
918
919
920
921
922
923
924
925
926
927
928
929
930
931
932
933
934
935
936
937
938
939
940
941
942
943
944
945
946
947
948
949
950
951
952
953
954
955
956
957
958
959
960
961
962
963
964
965
966
967
968
969
970
971
972
973
974
975
976
977
978
979
980
981
982
983
984
985
986
987
988
989
990
991
992
993
994
995
996
997
998
999
1000